January 28, 2014

MEMORANDUM TO: Kriss M. Kennedy, Director
Division of Reactor Projects
Region IV

FROM: Sher Bahadur, Deputy Director ***/RA/***
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

SUBJECT: FINAL RESPONSE TO TASK INTERFACE AGREEMENT 2013-05, CONTAINMENT INTERNAL STRUCTURES OPERABILITY CALCULATIONS AT FORT CALHOUN STATION

By letter dated April 12, 2013 (Agencywide Documents Access and Management System Accession No. ML13102A237), the U.S. Nuclear Regulatory Commission, Region IV Office requested technical assistance from the Office of Nuclear Reactor Regulation (NRR) to evaluate several calculations used to demonstrate the operability of containment internal structures (CIS) at Fort Calhoun Station (FCS) by providing answers to the Task Interface Agreement questions noted in Section 1.0 of the enclosed evaluation.

The NRR staff position is that Region IV inspectors should ensure that the appropriate FCS design drawings and/or procedures have been updated and the applicable procedures have proper control to maintain the values of live load for outage and operating conditions, within the limits considered in the CIS functionality assessment. This position and responses to the Region IV questions are documented in the enclosed evaluation.

Enclosure:
As stated

CONTACT: Holly D. Cruz, DPR/PLPB
(301) 415-1053

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ADAMS Accession No.: ML14016A260 **NRR-106**
***No changes from Draft TIA. As draft was issued prior to issuance of COM-106, Rev. 4, the Final response is being processed per Rev. 3.**

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TASK INTERFACE AGREEMENT 2013-05

FUNCTIONALITY ASSESSMENT OF CONTAINMENT INTERNAL STRUCTURES

CONCRETE FLOORS AT ELEVATIONS 1013, 1045, AND 1060 FEET

AT FORT CALHOUN STATION

1.0 INTRODUCTION

Fort Calhoun Station (FCS) discovered that several structural elements within the Containment Internal Structures (CIS) concrete floors at elevations (EL) 1013 feet (ft), 1045 ft, and 1060 ft did not comply with the FCS licensing basis requirements. To assess the functionality of the CIS concrete floors, Omaha Public Power District (the licensee) performed a reanalysis of the CIS concrete floors using GTSTRUDL computer software.

By letter dated April 12, 2013 (Agencywide Documents Access and Management System Accession No. ML13102A237), the U.S. Nuclear Regulatory Commission, Region IV Office, requested technical assistance from the Office of Nuclear Reactor Regulation (NRR) to evaluate several calculations used to demonstrate the operability of CIS at FCS by providing answers to the following Task Interface Agreement (TIA) questions:

1. Evaluate the overall acceptability of using GTSTRUDL computer software for the CIS operability evaluation, specifically:

    a. Assess the appropriateness of the structural model used in the analysis.
    b. Evaluate boundary conditions, member properties, modeling of mass, and assumptions included in the analysis.
    c. Review material properties for adequacy (use of 28 day concrete cylinder test data, cracked versus un-cracked section properties, damping, and ductility, etc.).

2. Evaluate the assumptions and methods used for the seismic analysis of the CIS (with particular attention to vertical, horizontal, and torsional stiffness, horizontal loads, soil-structure interaction, seismic amplification, response spectrum, etc.).

3. Since non-linear analysis was not used in the original design of the CIS floors at EL 1013 ft, 1045 ft, and 1060 ft, is it appropriate to use this method of analysis for an operability evaluation of the CIS?

4. Review Calculation 12Q4070-CAL-009 (FC08189) to assess whether the ACI 318-1963 design provisions have been properly used in the evaluation of the CIS beams and columns.

ENCLOSURE

2.0 BACKGROUND

The CIS is designated as Class I structure and designed in accordance with the requirements of ACI 318-63, "Building Code Requirements for Reinforced Concrete." As described in the FCS Updated Safety Analysis Report (USAR), Section 5.11.2, Class I structures were designed to ensure that their functional integrity under the most extreme environmental loadings, such as tornado or maximum hypothetical earthquake (MHE), will not be impaired and thereby, prevent a safe shutdown of the plant. As the CIS is located within the containment structure, wind and tornado loadings do not apply. As described in the FCS USAR, Section 5.11.3, Class I structures were designed for seismic loads as discussed in Appendix F of the USAR.

The CIS concrete floors at EL 1013 ft, 1045 ft, and 1060 ft support safety related equipment and systems that are necessary for safe operation, safe shutdown, and the ability to maintain safe shutdown of the reactor for those load combinations specified in the FCS USAR, Section 5.11.

As shown in the enclosure to TIA Request 2013-05, there are several calculations that supported the operability determination of the CIS concrete floors. TIA 2013-03 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML13017A072) is already under review and focuses on the containment pressure time history obtained from the computer program GOTHIC. The results of GOTHIC analysis are used to determine the pressure loading on the CIS concrete floor elements in the structural analysis. The additional calculations are predominantly a reconstitution of the permanent loads (self-weight, equipment load, commodity loads, pipe loads, etc.), and temporary/transient loads applicable to the CIS floors at EL 1013 ft, 1045 ft, and 1060 ft.

To respond to questions included in TIA Request 2103-05, the NRR staff's scope of review included FCS Calculation FC08164 (Reference 1) which outlines the methodology for development of GTSTRUDL finite element model and analysis. Also, the NRR staff reviewed Calculation FC08189 (Reference 2) to assess whether ACI 318-63 ultimate strength design provisions have been properly used in the evaluation of the CIS beams and columns. The information related to the reconstitution of the design basis of the CIS and conceptual design of any modifications to the CIS was not reviewed and was considered outside the scope of this TIA.

As noted in Calculation FC08189, the ultimate strength acceptance criteria of the ACI 318-63 Code were exceeded for nine beams (five beams at EL 1013 ft and four beams at EL 1045 ft). Calculation FC08189 references Calculation FC06971 which addresses the functionality of four beams at EL 1045 ft in the reactor vessel head laydown area, and Calculation FC08235 which includes a nonlinear analysis to determine the peak shear load capacity of beams B22a and B22b at EL 1013 ft. The review and acceptability of FCS Calculations FC06971 and FC08235 and the use of their results in Calculation FC08189 (Reference 2) to demonstrate functionality of the overstress condition of these nine beams, is outside the scope of this TIA.

3.0 EVALUATION

The following provides responses to the specific questions noted in TIA 2013-05:

Question 1

Evaluate the overall acceptability of using GTSTRUDL computer software for the CIS operability evaluation, specifically:

a) Assess the appropriateness of the structural model used in the analysis.
b) Evaluate boundary conditions, member properties, modeling of mass, and assumptions included in the analysis.
c) Review material properties for adequacy (use of 28 day concrete cylinder test data, cracked versus un-cracked section properties, damping, and ductility, etc).

Response 1a:

The licensee used GTSTRUDL structural analysis computer software to perform a linear elastic analysis to determine the shear force and bending moment demand for functionality assessment of the CIS concrete floor system. The following outlines some of the main features of the GTSTRUDL three-dimensional finite element model of the CIS:

i. The CIS beams and columns have been modeled using beam elements. The slab was not modeled. However, the licensee, according to Section 906 of ACI 318-63, considered an effective width of the slab in determining the beam sectional properties.
ii. The licensee assumed that the floor slab is rigid and will transfer the horizontal seismic inertia loads to the main vertical lateral load resisting elements including the steam generator (SG) and reactor coolant pump (RCP) compartment walls. In response to NRR staff's question, the licensee performed additional calculations and demonstrated the adequacy of the load path from the floor slab diaphragm to the vertical lateral load resisting elements.
iii. Rigid offset has been used at the end of the beam elements to model the eccentricity at the beam support interface and it allows the extraction of shear forces and flexural moments at the support interface.
iv. The CIS finite element model has mainly been constructed to study the structural behavior of the CIS concrete floors in the vertical direction (beam's major axis bending), similar to the original design basis calculations where manual hand calculations were performed to determine the shear load and flexural moment demand.

The NRR staff finds the use of GTSTRUDL computer software, which has been previously used for structural analysis of nuclear safety related structures, and the use of beam elements to represent the CIS concrete floor beams and columns acceptable for determining the shear load and flexural moment demand for functionality assessment of the CIS concrete floors.

Response 1b

I. Boundary Conditions

The GTSTRUDL model used for functionality assessment of the CIS concrete floors is fixed against displacement and rotation at the base mat level. This is a reasonable boundary condition considering the stiffness of the base mat and additional rigidity offered by the SG/RCP compartment walls.
Where the reinforcing steel lacked sufficient development into supporting members, the licensee released the moment in the GTSTRUDL finite element model. Where beams were framed into the SG/RCP compartment walls or reactor cavity walls, out of plane flexibility of the wall was considered and rotational springs were introduced for the boundary condition. The NRR staff finds the boundary conditions applied to the GTSTRUDL model reasonable.

II. Member Properties

See response to Question 1c.

III. Weight/Mass of Finite Element Model

The self-weight of the concrete beams and slabs are applied to the finite element model using the "density" command in GTSTRUDL. As the slabs are not included in the model, the total weight per unit length of the beams and tributary slab widths are determined, and this value is divided by the gross cross-sectional area of the beam to determine an equivalent density for the beam.

Floor live loads, weight of major equipment, commodity loads due to cable trays, conduits and small bore piping, and discrete loads due to large bore piping are included in the finite element model. For dynamic analysis of the CIS concrete floor system, 25 percent of the floor live load is considered present in addition to the self-weight of the structure and all other permanently affixed components which is consistent with the Standard Review Plan (SRP) 3.7.2 guidance.

The NRR staff finds the method of modeling of the mass/weight considered for static and dynamic analysis reasonable for the functionality assessment of the CIS concrete floors.

Response 1c

I. Use of 28 Day Concrete Cylinder Test Data

In Appendix E of Calculation FC08189 (Reference 1), the licensee justified the use of a design compressive strength, f'c, of 5500 pounds per square inch (psi) for the purpose of the functionality assessment of the CIS concrete floors. This was based on an analysis of 28-day concrete cylinder test data from the original construction using the provisions outlined in Section 504 of ACI 318-63. It is noted that the specified design compressive strength in the original design for the CIS concrete floors was 4000 psi.

Since the procedures described in ACI 318-63 are appropriate to investigate cylinder strength test results in the original (new) construction, the NRR staff performed an independent statistical analysis of the 28-day cylinder test data from the original construction of the CIS concrete floors. The NRR staff's statistical analyses indicated that with an overall mean value of the 28-day cylinder test data of approximately 6025 psi and a standard deviation of approximately 325 psi, there is approximately 5 percent probability that f'c will be less than 5500 psi.

Considering that the NRC regional inspectors did not identify any structural distress in the CIS concrete floor beams, columns, and slabs, the NRR staff finds the use of concrete compressive strength of 5500 psi reasonable for the functionality assessment of the CIS concrete floors at EL 1013 ft, 1045 ft, and 1060 ft. It should be noted that this evaluation and conclusion only applies to the FCS CIS functionality assessment and does not represent NRC staff's generic position on acceptance criteria for in-situ structural material strength.

II. Reinforcing Steel Yield Strength

The minimum yield strength of the reinforcing steel for the CIS is 40,000 psi. For the functionality assessment of the CIS, the licensee used a value of 44,100 psi for the reinforcing steel yield strength based on a statistical evaluation of the available test data from the original construction. The licensee demonstrated that there is approximately 6 percent probability that the yield strength of the reinforcing steel will be less than 44,100 psi.

Considering the above, the NRR staff finds the use of yield strength of the reinforcing steel of 44,100 psi (approximately 10 percent higher than the minimum specified yield strength) reasonable for the functionality assessment of the CIS concrete floors at EL 1013 ft, 1045 ft, and 1060 ft. It should be noted that this acceptance is specific to the functionality assessment of the CIS and does not represent NRC staff's generic position on acceptance criteria for in-situ structural material strength.

III. Material Properties

As noted above, concrete compressive strength of f'c=5500 psi was used for the functionality assessment of the CIS concrete floors. The concrete modulus of elasticity was determined according to Section 1102 of ACI 318-63. Density and Poisson's ratio of concrete was considered as 150 pounds per cubic foot (pcf) and 0.17, respectively. The NRR staff finds these input parameters used in the GTSTRUDL analysis acceptable for the functionality assessment of the CIS concrete floors.

IV. Member Sectional Properties

The licensee considered the effective width of the slab on both sides of the rectangular beam or only on one side of the rectangular beam, as applicable, according to Section 906 of ACI 318-63, to determine the beam sectional properties used in the GTSTRUDL analysis.

In addition, there is a 2-inch concrete topping applied over the entire area of the concrete slabs at all three EL, as shown on the FCS Drawings 11405-S-18 and 11405-S-19. The licensee considered the 2-inch concrete topping in determining the effective depth of 4 beams for determining moment capacity within the span of the beam (bottom reinforcement in tension). In addition, 2-inch concrete topping was considered in determining shear capacity at the end of the beam using Equation 17-2 of ACI 318-63, when the moment at the section created tension at the bottom reinforcement. The licensee provided the FCS original construction documentation indicating that the 2-inch concrete topping at EL 1045 ft and 1060 ft was placed monolithically with the concrete slab.

At EL 1013 ft, in response to the NRR staff's question, the licensee provided further information from the FCS original construction documentation that the concrete surface was prepared according to the applicable construction specification and performed additional calculation and demonstrated that there is adequate horizontal shear transfer at the interface between the concrete topping and the concrete slab/beam in compliance with Section 2505 of ACI 318-63. Accordingly, the NRR staff finds the approach of considering the 2-inch concrete topping effective for determining moment capacity within the span and shear capacity at the end of the beam acceptable for the functionality assessment of the CIS.

For the MHE load combinations, the licensee assigned moment of inertia of the beam elements equal to approximately half of the gross (uncracked) moment of inertia to account for cracking. This modeling technique which takes into account concrete cracking is in-line with the industry standards (ASCE/SEI 43-05) and the draft Revision 4 of SRP 3.7.2; thus, it is considered acceptable for the functionality assessment of the CIS for MHE load combinations.

V. Damping

The licensee used 4 percent and 7 percent structural damping for the operating basis earthquake (OBE) and MHE, respectively, in the CIS response spectrum analysis. These damping values are consistent with Regulatory Guide (RG) 1.61 damping values for reinforced concrete structures and are acceptable for the functionality assessment of the CIS concrete floors at EL 1013 ft, 1045 ft, and 1060 ft.

As noted in Section 2.6.3.2 of Calculation FC08164 (Reference 2), in order to determine the equipment loads imparted on the concrete floor framing members due to seismic overturning effects, the licensee used 1 percent damping for both OBE and MHE consistent with Table F-2 of Appendix F of the FCS USAR. The licensee also considered Section 2.2.2 of Appendix F of the FCS USAR where three groups of equipment (rigid, resonance, and flexible) are classified based on their natural frequency and the frequency of the supporting structure. Since the licensee used the FCS USAR damping values and methodology for equipment classification, the NRR staff finds this technical approach acceptable for the functionality assessment of the CIS concrete floors at EL 1,013 ft, 1,045 ft, and 1,060 ft.

VI. Inelastic Energy Absorption Factor

For the functionality assessment of the CIS concrete floors, the licensee used a factor of 1.25, to account for the inelastic energy absorption capability of the CIS structure, to reduce the seismic demand in the linear analysis performed using GTSTRUDL computer software.

Considering that the NRC regional inspectors did not identify any structural distress in the CIS concrete floors, and the fact that a factor of 1.25 represents limited inelastic excursion, the NRR staff finds the use of an inelastic energy absorption factor of 1.25 reasonable for the functionality assessment of the CIS concrete floors.

VII. Moment Redistribution

Section 1502(d) of ACI 318-63, the CIS design basis "Code of Record," allows a negative moment calculated by elastic theory to be adjusted up to 10 percent. In the functionality assessment of the CIS concrete floors, the beam bending moment at the end has been reduced up to 20 percent, as permitted by Section 8.6 of the ACI 318-71 Code, and the bending moment within the beam span has been increased, as appropriate. It should be noted that the moment redistribution has only been used for seven beams listed in Appendix G of Calculation FC08189. The NRR staff finds this approach acceptable for the functionality assessment of the CIS concrete floors because the maximum adjustment of the negative moment first permitted in the ACI 318-63 was considered conservative and later was increased to a maximum of 20 percent in ACI 318-71.

VIII. Load Combinations

As noted in Appendix F of the FCS USAR, Section 2.1.1:

> All Class I components, systems and structures are designed so that seismic stresses resulting from the response to a ground acceleration of 0.17g acting in the horizontal direction and two-thirds of 0.17g acting in the vertical direction simultaneously, in combination with the primary steady state stresses, are limited so that the function of the component, system or structure is not impaired in such a manner that a safe and orderly shutdown of the plant is prevented.

For the functionality assessment of the CIS floor system, the licensee used the "No loss of Function (NLF)" load combinations described in Section 5.11.3 of the FCS USAR, including differential pressure loading as a result of a major break in the reactor coolant system. For each load combination with seismic load, four horizontal directional cases were considered (N-S, E-W, S-N, and W-E) with both upward and downward seismic load in the vertical direction, i.e. a total of eight directional cases. The enveloping seismic demand was extracted from these eight cases.

The functionality assessment of the CIS floor system considered operational and outage loading conditions. During an outage, the equipment is moved and placed in certain locations, and a transient live load may be present due to maintenance. The live load values shown on the original FCS design drawings, 11405-S-18 and 11405-S-19 are 200 psf and 400 psf depending on the EL and area of the CIS concrete floors.

These values have been decreased to 100 psf and 200 psf (for outage condition), respectively, in the CIS functionality assessment documented in Calculation FC08189. For the operational loading condition, no live load was considered as gravity loads are taken to be non-transient for the duration of operation.

In response to an NRR staff's question, the licensee indicated that the FCS Operational Instruction OI-CO-1, "Containment Closeout," dictates the use of laydown areas inside the containment and Procedures SO-M-101, "Maintenance Work Control," and FCSG-22-13, "Containment Outage Manager," are being revised to ensure that the containment coordinator, in conjunction with the lead craft, will ensure that loads due to equipment, tool, and material staging in containment, do not exceed the allowable live load for outage and operating conditions.

Recommended action for Region IV:

Since the values of live load during outage and operating conditions play a critical role in the functionality assessment of the CIS concrete floors, Region IV inspectors should ensure that the appropriate FCS design drawings and/or procedures have been updated and the applicable procedures have proper control to maintain the values of live load for outage and operating conditions, within the limits considered in the CIS functionality assessment.

Question 2

Evaluate the assumptions and methods used for the seismic analysis of the CIS (with particular attention to vertical, horizontal, and torsional stiffness, horizontal loads, soil-structure interaction, seismic amplification, response spectrum, etc.).

Response 2

Section 2.2, "Methods of Analysis for Class I Structures and Components" of the FCS USAR, Appendix F, notes that:

> The following methods of analysis were applied to Class I structures, systems and equipment:
> a) The natural frequency of vibration of the structure or component was determined.
> b) The response acceleration of the component to the seismic motion was taken from the response spectrum curve at the appropriate natural frequency and damping factor.

The licensee performed a fixed base response spectrum analysis of the CIS concrete floor using GTSTRUDL to determine the seismic demand. The vertical in-structure response spectra, Figure F-26 (5 percent damping, OBE) and Figure F-27 (7 percent damping, MHE), from Appendix F of the FCS USAR, adjusted with an inelastic energy absorption factor of 1.25 (discussed in Response 1c) and damping of 4 percent (OBE), were applied at the base mat level (GTSTRUDL support location for the CIS floor finite element model).

The modal responses were combined using the Double Sum method and the residual rigid response of the missing mass modes was considered. This is consistent with the guidance in RG 1.92.

The licensee considered the concrete floor slab as rigid transferring the entire horizontal seismic loads to the SG/RCP compartment walls and assumed that the columns will resist lateral loads due to only self-weight. In response to NRR staff's question relative to EL 1060 ft, the licensee performed an additional calculation to demonstrate the validity of this assumption and determined the percent of the lateral force distributed to the circumferential framing members.

The NRR staff finds that the overall approach of response spectrum analysis using GTSTRUDL computer software is acceptable for the functionality assessment of the CIS concrete floor because: (1) this analysis approach directly accounts for the potential response amplification due to the frequency content of the CIS beams and it generates the bending moment and shear force seismic demand; (2) the FCS USAR, Appendix F, Figures 26 and 27, indicate that the in-structure response spectra shown in these figures are applicable to all EL of the reactor and auxiliary buildings; (3) and the modal response combination used in the response spectrum analysis is consistent with the guidance described in RG 1.92.

<u>Question 3</u>

Since non-linear analysis was not used in the original design of the CIS floors at EL 1013 ft, 1045 ft, and 1060 ft, is it appropriate to use this method of analysis for an operability evaluation of the CIS?

<u>Response 3</u>:

As noted in the FCS USAR, the CIS was designed according to the ACI 318-63 provisions; thus, the CIS was designed to remain essentially elastic. The FCS USAR does not include any information relative to the applicability of a non-linear analysis methodology being used to determine the structural adequacy of the CIS.

The SRP 3.7.2 provides the following guidance:

> The SRP acceptance criteria primarily address linear elastic analysis coupled with allowable stresses near elastic limits of the structures. However, for certain special cases (e.g., evaluation of s-built structures), reliance on limited inelastic/nonlinear behavior when appropriate is acceptable to the staff. Analysis methods incorporating inelastic/nonlinear considerations and the analysis results are reviewed on a case-by-case basis.

Section C.4, "Use of Alternative Analytical Methods in Operability Determinations," of the NRC Inspection Manual Part 9900 notes the following:

> When performing operability determinations, licensees sometimes use analytical methods or computer codes different from those originally used in the calculations supporting the plant design. This practice involves applying "engineering judgment" to determine if an SSC remains capable of performing its specified safety function during the corrective action period. The use of alternative methods is not subject to 10 CFR 50.59 unless the methods are used in the final corrective action.

Considering the above, the NRR staff finds that it is acceptable for the licensee to use a non-linear finite element analysis method, incorporating inelastic material response, to demonstrate functionality of those CIS elements that are not in compliance with the ACI 318-63 Code provisions provided that: (1) the nonlinear analytical method is properly implemented and the structural model appropriately represents the CIS concrete floor elements; (2) the structural model and results are satisfactorily benchmarked, preferably using experimental test results, to ensure the analytical method and modeling techniques do not over-predict the strength of the structure; (3) the acceptance criteria represent a limited non-linear excursion; (4) the functionality of those components supported by the CIS concrete floor elements, including the adequacy of the anchorage, is demonstrated considering the predicted inelastic deformation and potential cracking; (5) the uncertainties of the model and its underlying input parameters are addressed; and (6) the use and verification/validation of the computer software is controlled in accordance with the licensee's quality assurance program.

<u>Question 4</u>

Review Calculation 12Q4070-CAL-009 (FC08189) to assess whether the ACI 318-63 design provisions have been properly used in the evaluation of the CIS beams and columns.

<u>Response 4</u>

The review of Calculation FC08189 was limited to implementation of the ultimate strength design (USD) code provisions outlined in ACI 318-63 for the functionality assessment of the CIS beams and columns. The licensee performed an evaluation of the beams and columns by formulating the applicable USD provisions of ACI 318-63 in Mathcad worksheets in parametric form. The same Mathcad formulation was used to evaluate all beams and columns. Therefore, the NRR staff reviewed a sample of a beam and a column worksheet to determine whether the applicable code provisions were appropriately implemented.

For the functionality assessment, the beams and columns were all evaluated by the USD method for the NLF load combinations. The evaluation of beams was performed separately, at each beam end and mid-span, for the structural demand in moment and shear demand, at two ends of the beam, for each load combination. Interaction ratios for shear and moment were calculated as the ratio of demand to capacity. The evaluation of the columns was performed separately, at the top and bottom of the column, for the appropriate structural demand in moment about two axes (biaxial bending) and axial load, due to the NLF load combinations. The ultimate axial capacity was determined for the two ends and interaction ratios were calculated, as the ratio of demand to ultimate axial capacity, for the two ends. The relevant code provisions implemented in Calculation FC08189 are summarized below:

a) The evaluation of the beams was performed using the USD provisions in Chapter 15 (general requirements), Chapter 16 (flexure), and Chapter 17 (shear) of ACI 318-63.
b) The material properties for yield strength of reinforcing steel of fy = 44.1 ksi and concrete compressive strength of f'c = 5500 psi, were used in the evaluation. The validity of f'c and fy values are discussed in Response 1c.
c) Values of modulus of elasticity for concrete and steel were appropriately considered in accordance with Sections 1102 and 1103 of the ACI 318-63 Code.
d) Capacity reduction factors (ϕ) of 0.9 for flexure, 0.85 for shear, and 0.7 for tied compression members were appropriately used per Section 1504 of ACI 318-63.
e) The ultimate moment capacity, Mu, of the beams was appropriately calculated using equations in Section 1601 and 1603 of the ACI 318-63 Code, including considering the beams as T-sections due to monolithic construction with the floor slab. Both cases of deep slab and shallow slab (i.e., flange thickness equal to or exceeding the neutral axis depth) were considered using the code provisions in Sections 1603(a) and (b), respectively.
f) Shear was evaluated in a section, at distance, d (effective depth) from the face of the support, as allowed by Section 1701(d) of ACI 318-63.
g) Shear capacity was appropriately determined using ACI 318-63 Code provisions in 1701(d) for concrete and 1703(a) for stirrup reinforcement.
h) The evaluation of the columns was performed using the USD provisions in Chapter 9 and 15, with regard to general requirements, and Chapter 19 of ACI 318-63, for combined axial compression and bending.
i) The bending and axial load capacity of the columns were determined using the equations and provisions in Section 1902 of the ACI 318-63, applicable to short members of rectangular sections with bars in one or two faces. The columns were justified to be considered short based on the criteria of $L/r < 60$, per Section 916 of the ACI 318-63 Code, where L is the unsupported length of the column and r is the radius of gyration of gross concrete area of the column.
j) The effect of horizontal seismic acceleration was considered, to determine the additional demand on the column, due to self-weight.
k) The ultimate capacity of the column was determined in accordance with the provisions in Section 1902 of the ACI 318-63 Code. The two cases (i) when the section is controlled by tension and (ii) when the section is controlled by compression were appropriately considered and evaluated, in accordance with the equations in paragraphs 1902(c)(1) and 1902(c)(2), respectively. The ultimate capacity for biaxial bending was determined using the Bressler method, explained in the commentary for Section 1905 of ACI 318-63.

In summary, the NRR staff finds that the licensee has appropriately implemented the applicable USD provisions of ACI 318-63 for axial, flexure, and shear capacity evaluation of the CIS beams and columns.

4.0 CONCLUSION

Based on the review of the FCS USAR, Calculations FC08189 and FC08164, and additional information provided by the licensee in response to the NRR staff's questions, the NRR staff provided the requested technical guidance relative to the questions raised by Region IV in the TIA 2013-05. The following provides an overall summary of the technical guidance and recommended actions:

a) The use of GTSTRUDL computer software, which has been previously used for structural analysis of nuclear safety related structures, and the use of beam elements to represent the CIS concrete floor beams and columns are acceptable for determining the shear load and flexural moment demand.
b) The boundary conditions, material properties input parameters, and member sectional properties used in the GTSTRUDL analysis are reasonable.
c) The use of concrete compressive strength of 5500 psi, and yield strength of the reinforcing steel of 44,100 psi, are reasonable.
d) The method of modeling of the mass/weight considered for static and dynamic analysis is reasonable.
e) The structural damping values of 4 percent and 7 percent for the OBE and MHE, respectively which are consistent with RG 1.61 damping values for reinforced concrete structures are acceptable.
f) The use of an inelastic energy absorption factor of 1.25 to reduce the seismic demand in the linear analysis is reasonable for the functionality assessment of the CIS concrete floors.
g) The use of moment redistribution of up to 20 percent, as permitted by Section 8.6 of the ACI 318-71 Code, is acceptable.
h) The live load values shown on the original FCS design drawings, 11405-S-18 and 11405-S-19 are 200 psf and 400 psf depending on the EL and area of the CIS concrete floors. These values have been decreased to 100 psf and 200 psf (for outage condition), respectively, in the CIS functionality assessment documented in Calculation FC08189. For the operational loading condition, no live load was considered as gravity loads are taken to be non-transient for the duration of operation.

Recommended action for Region IV:

Since the values of live load during outage and operating conditions play a critical role in the functionality assessment of the CIS concrete floors, Region IV inspectors should ensure that the appropriate FCS design drawings and/or procedures have been updated and the applicable procedures have proper control to maintain the values of live load for outage and operating conditions, within the limits considered in the CIS functionality assessment.

i) The overall approach of response spectrum analysis using GTSTRUDL computer software is acceptable for the functionality assessment of the CIS concrete floor.

j) It is acceptable for the licensee to use a non-linear finite element analysis method, incorporating inelastic material response, to demonstrate functionality of those CIS elements that are not in compliance with the ACI 318-63 Code provisions provided that the conditions outlined in the response to Question 3 are satisfied.

k) The licensee has appropriately implemented the applicable USD provisions of ACI 318-63 for axial, flexure, and shear capacity evaluation of the CIS beams and columns.

5.0 REFERENCES

1. Fort Calhoun Station Calculation No. FC08164, Revision 0, Criteria and Methodology for Fort Calhoun Containment Internal Structure Analysis and Redesign.
2. Fort Calhoun Station Calculation No. FC08189, Revision 1, Evaluation of Operability – Containment Internal Structure, Fort Calhoun Station.
3. Fort Calhoun Station Updated Safety Analysis Report.
4. Memorandum to Sher Bahadur from Kriss M. Kennedy, Request for Technical Assistance-Fort Calhoun Station Containment Internal Structures Operability Calculations, dated April 12, 2013 (ADAMS Accession No. ML13102A237).

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Date: January 28, 2014